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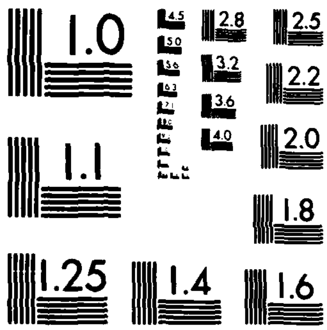

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CLUTTER PROCESSING OF SEEK IGLOO A MODERN LONG RANGE 3-D RADAR

By
R. C. SMITH

APRIL 1983

Prepared for

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This technical report has been reviewed and is approved for publication.

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The different types of processing that the SEEK IGLOO radar uses to enhance target d tection in clutter environments are discussed. This paper was presented at the Electro '82 Convention in Boston in May, 1982.

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1.0 INTRODUCTION AND BACKGROUND

The SEEK IGLOO radar is being developed by the General Electric Company under a contract with the United States Air Force Electronic Systems Division (ESD). The MITRE Corporation acts as systems engineers in support of ESD. The radar is being developed to replace the outmoded and expensive to maintain AN/FPS-93 and AN/FPS-90 radars now used in Alaska. The AN/FPS-93 is a two-dimensional surveillance radar and the AN/FPS-90 is a two-dimensional height finder radar; both of these older radars have been in operation since the early 1950's.

The specification requirements for SEEK IGLOO were set by a combination of the following: 1) performance characteristics of the AN/FPS-90 and AN/FPS-93 radars; 2) performance characteristics of the Semi-Automatic Ground Environment (SAGE) System and the Joint Surveillance System (JSS); 3) sensor requirements using the new generation fighter aircraft; and 4) stringent reliability, maintainability and availability requirements to reduce on-site maintenance and operations personnel. The radar being developed under the MITRE-supported SEEK IGLOO program will have to operate in Alaska's extreme environmental conditions, including a wide temperature range, non-homogeneous terrain clutter, poor weather, and a large population of ducks and geese.

The SEEK IGLOO radar will provide digital output messages (as opposed to the conventional "blip" signals used with many radar displays) containing range, azimuth and height information for radar and beacon targets. Therefore, because clutter returns will appear as radar targets, false reports due to clutter must be kept to a minimum.

This paper describes some of the methods of clutter and signal processing which will be used by the SEEK IGLOO radar.

These methods are currently being refined as part the of SEEK IGLOO pre-production test program.

1.1 SEEK IGLOO Description

The SEEK IGLOO radar is a frequency agile L-Band radar. The array antenna mechanically rotates in azimuth at five rpm, and an electronically-controlled pencil beam scans in elevation to provide tri-coordinate radar data and bi-coordinate beacon data on all targets within the specified coverage. (See Table I.) The radar transmitter consists of distributed solid state transmitter modules mounted behind the array; the receiver has the same configuration. After the receiver replies are superheterodyned to base band, the radar data are converted to digital signals for processing in real time. There is no video output per se, only digital messages giving spatial coordinates of the radar and beacon replies. The digital messages are then transmitted to the desired location for presentation on a Random Access Plan Position Indicator (RAPPI) or any other display capable of utilizing digital information.

1.2 Adverse Clutter Environmental Conditions

The clutter environment in Alaska is difficult for radar operation because of unique terrain, a wide range of temperatures, extreme weather, and a large migratory bird population. Each of these parameters was characterized in an appendix of the SEEK IGLOO system specification.

The terrain was divided into three separate areas: 1) a swampy area, known in Alaska as Muskeg or Tundra, which has a low scattering coefficient but a wide spectral distribution; 2) the Brook's Mountain Range, which has a larger scattering coefficient than Muskeg but a narrower spectral distribution; and 3) the McKinley Mountain Range, which has the same spectral distribution as the Brook's Mountain Range but a much larger scattering coefficient. (For a more detailed discussion of the terrain clutter, see Reference One.)

Some of the SEEK IGLOO radars will be located on coastal sites, making sea clutter an additional problem. According to the SEEK IGLOO System Specification, the sea clutter is considered to have a Rayleigh amplitude distribution with a mean scattering coefficient for sea state 5. The spectral distribution is considered Gaussian with the mean frequency value having a 3 dB width corresponding to 2.5 meters per second. This mean frequency may have any value corresponding to a doppler between -2.5 meters per second and +2.5 meters per second.

TABLE I

MAJOR SYSTEM CHARACTERISTICS

Characteristic	Parameter
Frequency Band	1215–1400 MHz
Instrumented Range	5–200 n.m.
Elevation Coverage	-6 degrees to +20 degrees
Altitude Limit	100,000 feet
Azimuth Coverage	360 degrees per 12 seconds
False Alarm rate per 360 degrees	
Noise	5
Terrain & Sea Clutter	20
Birds	70
Weather	100
Range Resolution	.5 n.m.
Range Accuracy	.25 n.m.
Height Accuracy	± 3000 ft. to 100 n.m. and 60,000 ft. ± 6000 ft. to 100–200 n.m. and 100,000 feet
Azimuth Accuracy	.18 degrees
Azimuth Resolution	2.0 degrees

The SEEK IGLOO radar also has to contend with rain. The rain has been modeled from Nathanson[3], and is bounded with a radial velocity of 25 meters per second, an atmospheric turbulence of one meter per second, and a wind shear gradient of 4.0 meters per second per kilometer of altitude. The rainfall rate was divided into two models: 1) an evenly distributed constant rainfall of two millimeters per hour; and 2) 120 rain cells distributed evenly within a 100 mile radius of the radar. Each of these 120 cells has a 2.6 mile diameter core with 10 millimeter per hour rainfall tapering linearly at 7.14 millimeters per hour per mile, resulting in an overall cell with a 5.4 mile diameter.

Alaska is also a principal breeding area for large migratory birds, which can appear as "targets" on radar screens. The SEEK IGLOO radar has to overcome this added target load. The major characteristics of the bird flocks are listed in Table II.

1.3 Signal Processing

The SEEK IGLOO radar employs several types of signal and digital processing techniques to reduce the clutter signals and enhance the desired radar targets. This processing dynamically adapts to changing environmental conditions to ensure that performance is not degraded. Processing techniques to reduce the unwanted masking of targets by "clutter" and enhance the target replies are: radiation of two contiguous pulses separated by 15 MHz; radiation pattern consisting of a narrow pencil beam with low sidelobes; phase nulling; large dynamic range; three and four pulse Moving Target Indicators (MTI); Fast Fourier Transform (FFT)/Doppler filtering; clutter mapping; a sliding window threshold; pre-radiation threshold control; and a bird filter. These techniques are used in combinations selected automatically as a function of elevation beam, azimuth sector, and environmental conditions. The contributions of each of these techniques are discussed in the following section.

TABLE II

BIRD CLUTTER MODELS

	Model A (Ducks & Geese)	Model B (Cranes)
Frequency Occurence	May–November	1 week in May (Peak): 1 Month, May/June and Aug/Sept
Number of Flocks	500 75% - 0 to 50 n.m. 25% - 50 to 100 n.m.	40 75% - 0 to 50 n.m. 25% - 50 to 100 n.m.
Number of Birds/Flock	30–150	20–2000
Dimensions of Flock	200 ft x 200 ft	5 n.m. x 1 n.m.
Individual Bird Cross-Section	0.02 m2	0.04 m2
Ground Speed	20–80 kts	20–80 kts
Altitude and Distribution	50% - 0 to 500 ft 25% - 500 to 5000 feet 25% - 5000 to 10,000 feet	80% - 0 to 5000 feet 20% - 5000 to 10,000 feet

2.0 METHODS OF PROCESSING

2.1 Radiation of Two Contiguous Pulses

Two pulses are used in all beams; each pulse pair is separated by 15 MHz, but each pulse is modulated with identical linear frequency modulated (LFM) envelopes. There are two sets of these pulses, one for short-range and one for long-range. The short-range sub-pulse bandwidth is 1.25 MHz, with a sub-pulse width of 51.2μ seconds so that the LFM Bandwidth Time (BT) product is 64 to 1. The long-range sub-pulse bandwidth is 0.625 MHz, with a sub-pulse width of 409.6μ seconds producing an LFM BT of 256 to 1. Independent samples of ground clutter returns, obtained by using the two contiguous sub-pulses, are used in setting target decision thresholds.

2.2 Radiation Pattern

The radiation pattern consists of a 2.2 degree pencil beam divided into short-range and long-range transmission intervals. Sixteen beams are required to cover the specified elevation space. (See Figure 1.) The pointing angle of each beam has been chosen to help reduce second-time-around returns from the previously transmitted beam.

Since the specified ground clutter is only significant in the low angle beams, only the low angle beams have repeat transmissions to enable multiple pulse filtering.

2.3 Phase Nulling

SEEK IGLOO antenna specifications require 90% of all sidelobes to be 36 dB below the main beam, and the average of all sidelobes to be 42 dB below the main beam. However, the sidelobes close to the mainbeam are much higher than these specified values. When the pencil beam is steered to the elevations where multiple pulse filtering is not employed, i.e., the upper beams, clutter returns can be received in the sidelobes and mask small target returns in the main beam. A phase nulling technique is employed in these cases to reduce the sidelobes in the areas where they intercept clutter sources to a two-way level of 67 dB below the main beam. This reduction of clutter intake in those sidelobes negates the need for multiple pulse filtering. Figure 2 illustrates the requirement for using the Phase Nulling technique. The sidelobes illuminating the close-in clutter or mountain clutter would be nulled, thereby reducing the level of signal reflected from the clutter.

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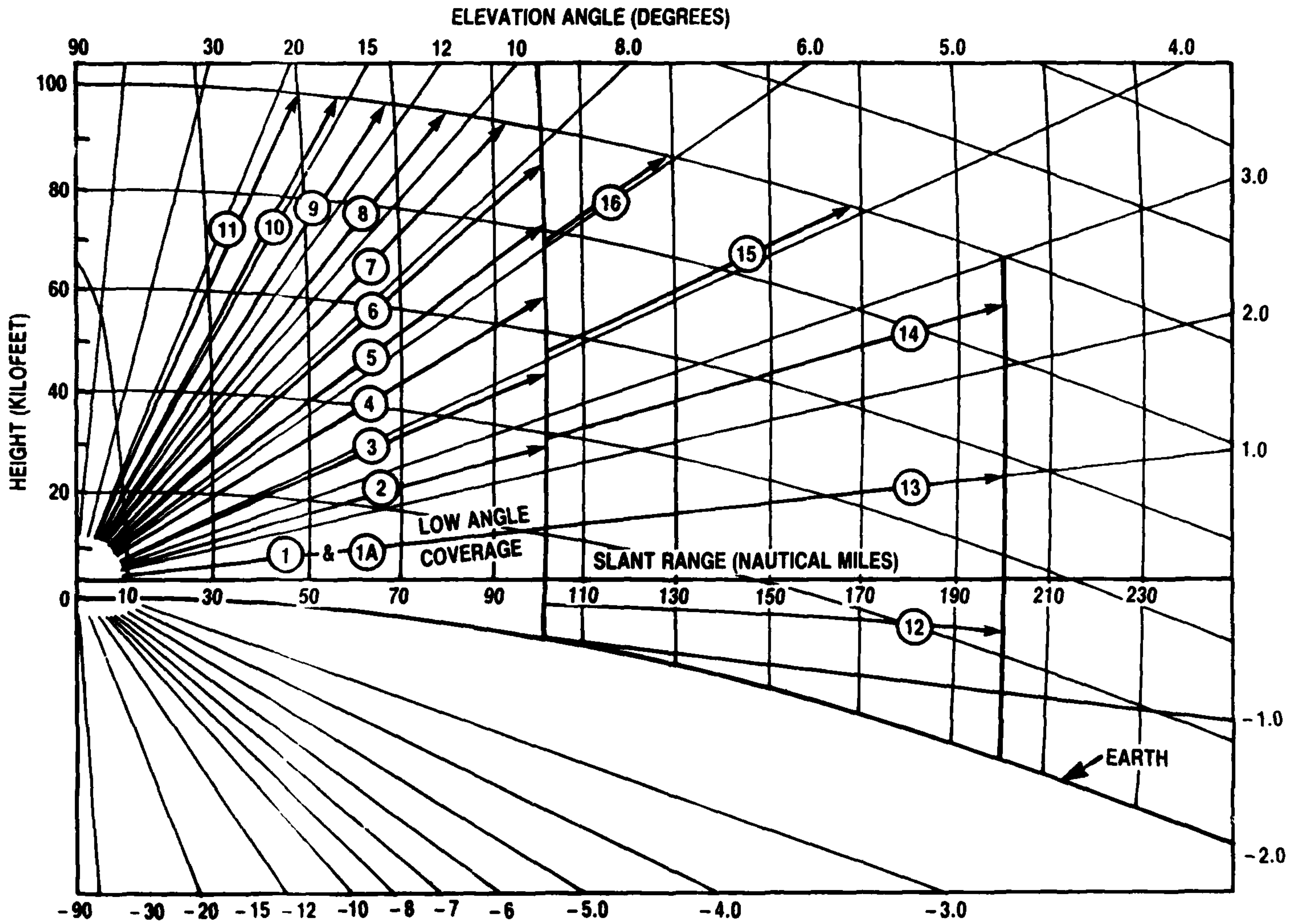


Figure 1. SEEK IGLOO RADAR RADIATION PATTERN

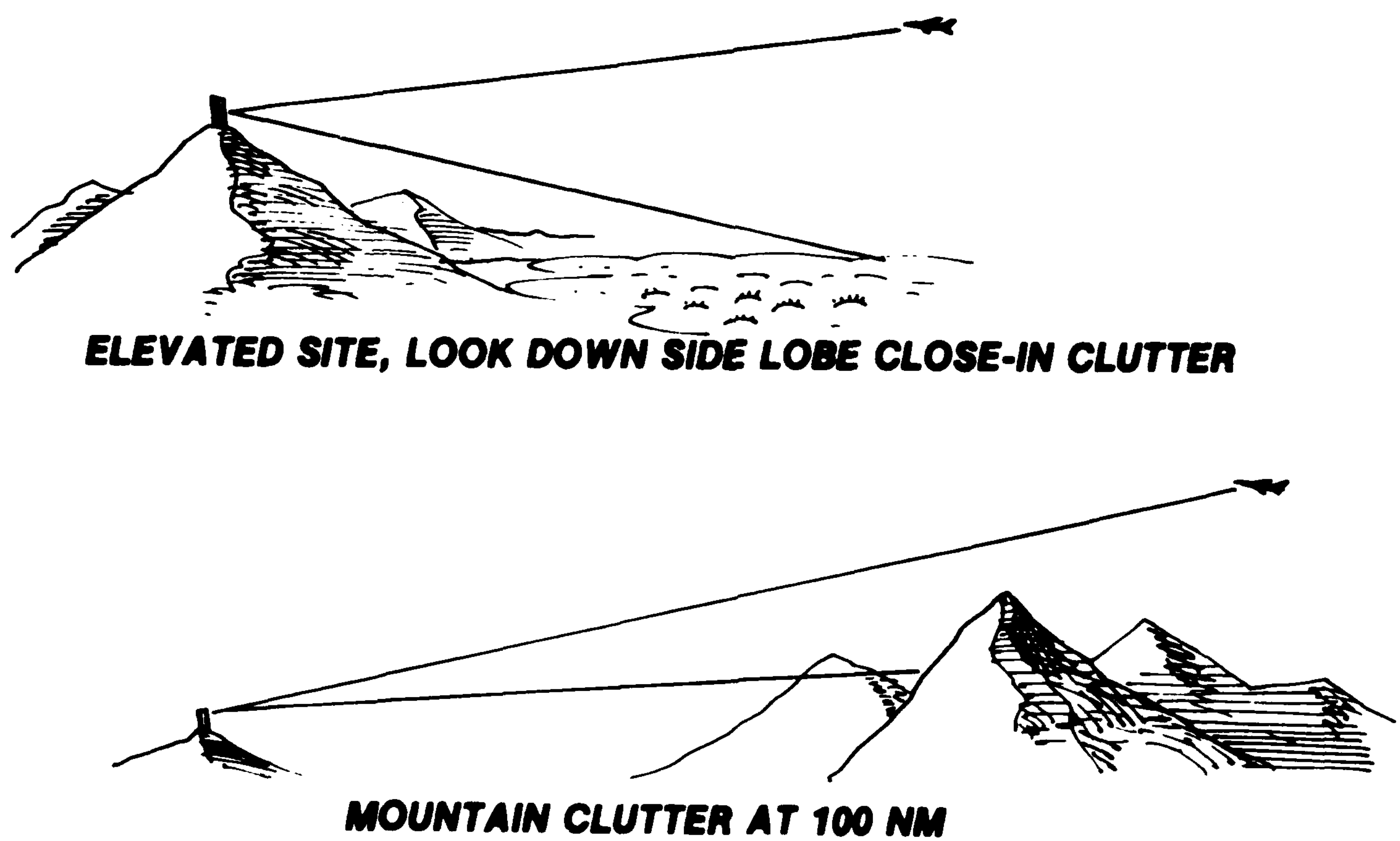


Figure 2. Clutter Environment Requiring Phase Nulling

2.4 Large Dynamic Range

To ensure the performance of multiple pulse filtering, the receiving system must operate linearly. The SEEK IGLOO uses digital Sensitivity Time Control (STC) to extend the dynamic range of the receiver by 48 dB. The STC is preprogrammed for each beam and type of clutter encountered. In addition to the large dynamic range of the receiver, a 12-bit A/D converter is used to convert the receiver signals to digital pulses for processing.

2.5 Moving Target Indicator (MTI)

Two separate MTI's are used; a three-pulse MTI is used to remove stationary clutter, and a four-pulse MTI is used to remove either stationary or moving clutter.

The three-pulse MTI is used in conjunction with an eight point Fast Fourier Transform/Doppler Filter in the lowest angle short-range beams where the stationary clutter is extremely intense; the three-pulse MTI is used alone in the second lowest short-range beam. The clutter rejection is 55 dB.

The four-pulse MTI has a variable rejection notch which can be varied 250 Hz. (See Figure 3.) The four-pulse MTI is used in the long-range beams where stationary clutter is not a problem, but where weather clutter can mask targets. The clutter rejection is also 55 dB.

2.6 Fast Fourier Transform (FFT)/Doppler Filter

An eight-point FFT and a bank of eight Doppler filters are used to coherently integrate signals into discrete Doppler frequency components. The signal-to-noise ratio of moving targets is enhanced from clutter signals which have no or low Doppler frequencies.

2.7 Clutter Map

A clutter map is generated using the signals from the zero Doppler filter in the FFT/Doppler Filter processing. The clutter map is used to set thresholds for clutter breakthroughs and reduce the false alarm rate.

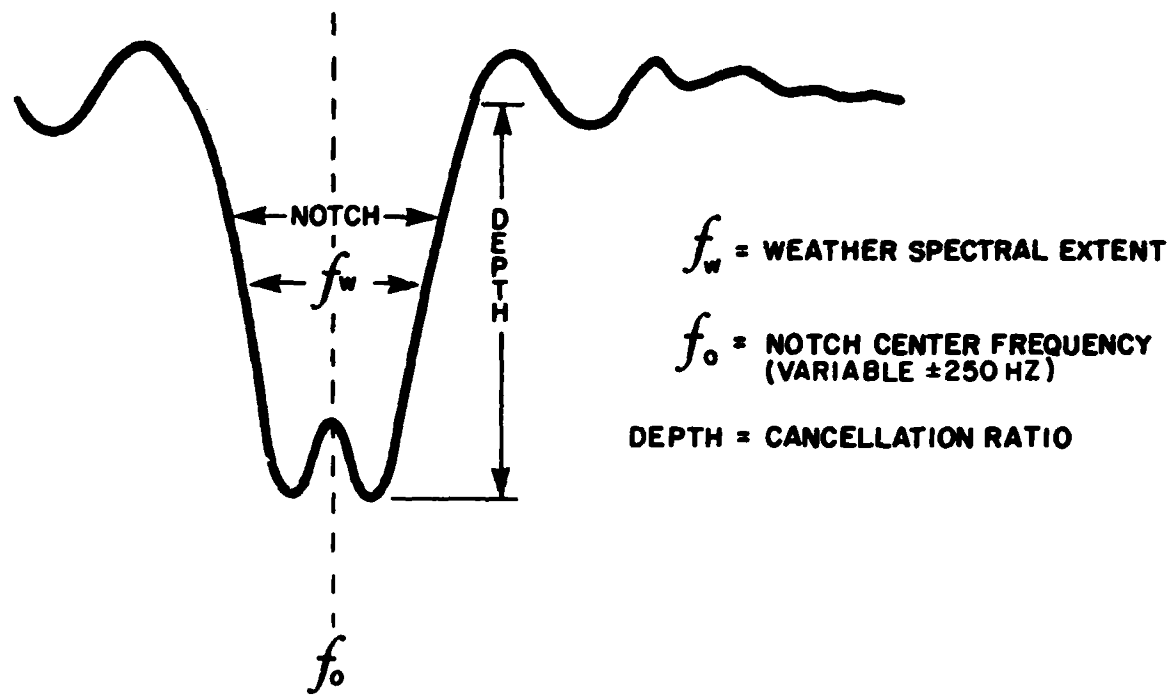


Figure 3. MTI Rejection Notch

2.8 Sliding Window Threshold

A threshold level to set the Probability of False Alarms (PFA) to 10^{-5} from noise is established by integrating the noise level in the eight range cells on each side of a given target window (which is three range cells in size). The target window "slides" in time from the minimum to the maximum range, constantly establishing the detection threshold for any given range at any instant in time.

2.9 Pre-Radiation Threshold Control

Prior to the transmission of any beam, the receive beam is steered to the desired location and the environment is monitored for ambient noise. The noise level is then used to establish a threshold for a PFA of 10^{-6} for that beam location. Figure 4 illustrates the pre-radiation threshold control.

2.10 Bird Filter/Stationary Target Discriminator

Some birds and stationary targets will not be filtered out by the signal processing hardware. Therefore, a tracker has been included in the radar software to detect slow-moving or stationary targets. The tracker monitors these reports for four scans to preset constants before declaring a bird or a stationary target. Once a target is declared a bird or stationary, no target reports will be generated by the radar.

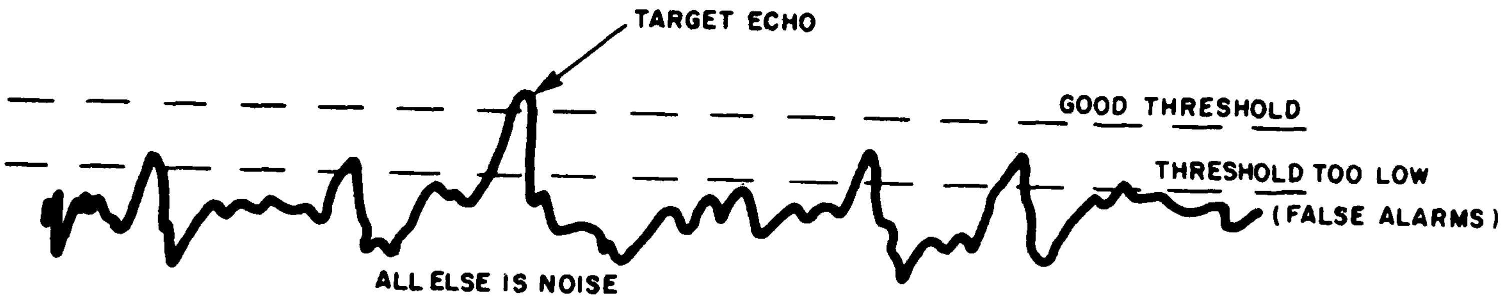


Figure 4. Treshold Control

3.0 SUMMARY

The techniques described above are used in many combinations to reduce clutter and to enhance the detectability of targets.

In the presence of heavy clutter, a heavy clutter combination of three-pulse MTI and FFT/Doppler filters is used with the sliding window threshold and the pre-radiation threshold to achieve a 58 dB reduction in clutter-to-noise ratio for the 5 to 100 n.m. range. In the 100 to 160 n.m. range, a four-pulse MTI is used to reduce the clutter.

In rain clutter, the heavy clutter processing combination is used for the 5 to 100 n.m. range. For the 100 to 160 n.m. range, a variable four-pulse integrate-and-dump MTI is used. The variable MTI has a movable filter notch which can be varied around a zero Doppler frequency (plus or minus 250 hertz) to cancel rain moving up to 25 meters per second.

For the beams which do not use filtering and experience clutter returns through sidelobes, a phase nulling technique is employed to reduce the clutter intake. This phase nulling is centered only over sidelobes which produce clutter returns.

All of the processing in the SEEK IGLOO radar is completely adaptable and under software control. Any parameter required for a given location or situation can be changed by a simple site adaption parameter added via the system software.

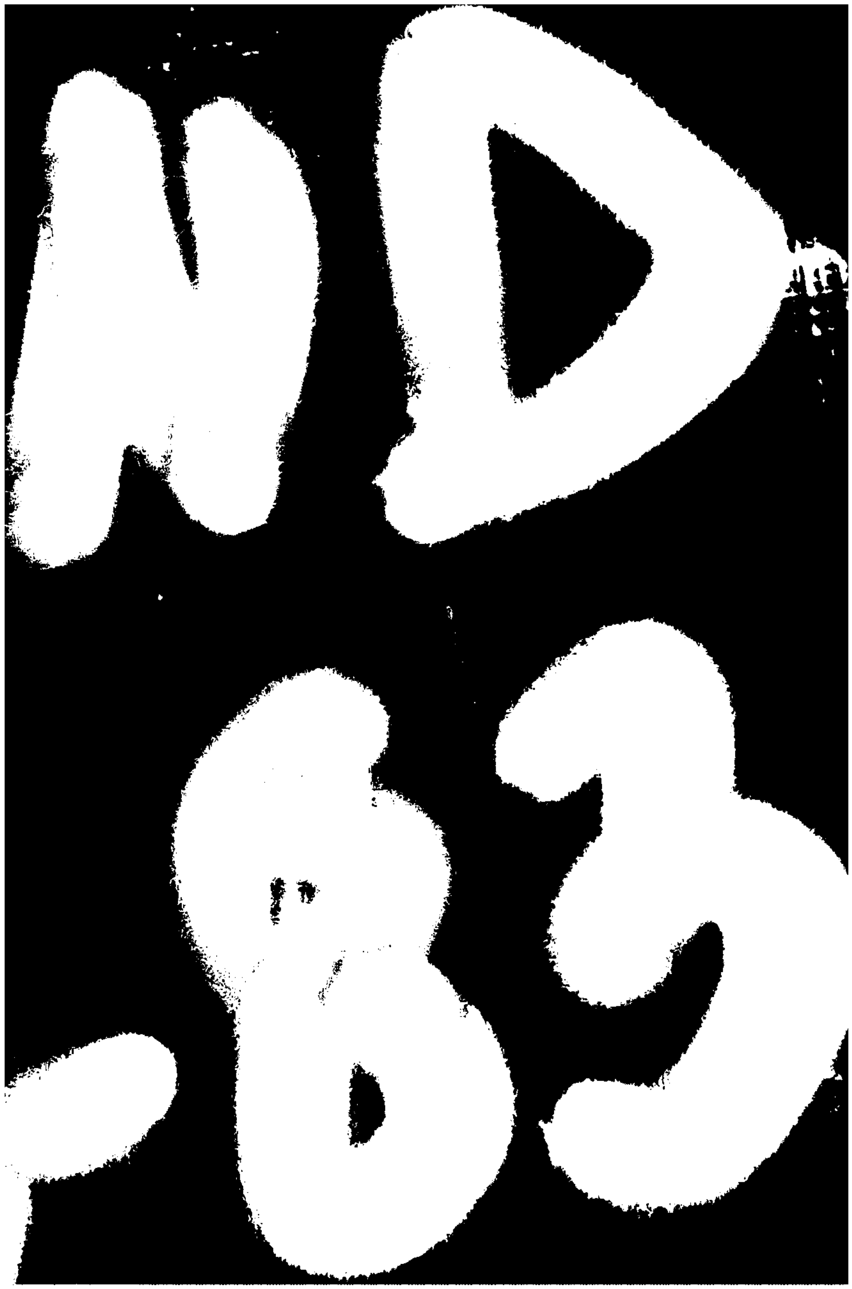
REFERENCES

1. J. Ryan, W. L. Simkins, and V. Vannicola, "SEEK IGLOO Radar Clutter Report," RADC TM-76-18, Rome, New York: Rome Air Development Center, December 1976, AD A047 897.

2. Fred E. Nathanson, Radar Design Principles, New York: McGraw-Hill, 1969.

GLOSSARY OF ACRONYMS

AN/FPS-90	Two-Dimensional Height Finder Radar presently used in Alaska
AN/FPS-93	Two-Dimensional Surveillance Radar presently used in Alaska
AN/FPS-117(V)	New Three-Dimensional SEEK IGLOO Radar
BT	Bandwidth Time
ESD	Electronic Systems Division (USAF Systems Command)
FFT	Fast Fourier Transform
JSS	Joint Surveillance System
LFM	Linear Frequency Modulated
MAR	Minimally Attended Radar
MTI	Moving Target Indicator
PFA	Probability of False Alarm
RAPPI	Random Access Plan Position Indicator
SAGE	Semi-Automatic Ground Environment
STC	Sensitivity Time Control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